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COMBINED CHARACTERISATION OF GOME AND TOMS TOTAL OZONE USING GROUND-BASED OBSERVATIONS FROM THE NDSC

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ABSTRACT

Several years of total ozone measured from space by the ERS-2 GOME, the Earth Probe TOMS, and the ADEOS TOMS, are compared with high-quality ground-based observations associated with the Network for the Detection of Stratospheric Change (NDSC), over an extended latitude range and a variety of geophysical conditions. The comparisons with each spaceborne sensor are combined altogether for investigating their respective solar zenith angle (SZA) dependence, dispersion, and difference of sensitivity. The space- and ground-based data are found to agree within a few percent on average. However, the analysis highlights for both GOME and TOMS several sources of discrepancies, including a dependence on the SZA at high latitudes and internal inconsistencies.

INTRODUCTION

Remote sensing from a satellite platform provides unique access to the required continuous measurements of relevant atmospheric trace species on the global scale. Space-based, long-term mapping of the global distribution of atmospheric ozone started with the NASA Total Ozone Mapping Spectrometer (TOMS) onboard Nimbus-7, from October 1978 to May 1993, and continued with a second TOMS onboard Meteor-3, from August 1991 to December 1994 (Heath *et al.*, 1975; McPeters *et al.*, 1996). Launched by ESA in April 1995 onboard its ERS-2 environmental satellite, the Global Ozone Monitoring Experiment (GOME) provides routinely the global picture of atmospheric ozone, as well as the abundance of other relevant trace species, such as NO_2, BrO, OClO, SO_2, and CH_2O (ESA, 1995; Burrows *et al.*, 1998). Since July 1996, a third TOMS monitors total ozone onboard the Earth

Probe platform (TOMS-EP), and a fourth TOMS operated aboard the Japanese ADEOS spacecraft (TOMS-AD) from September 1996 until the failure of ADEOS on June 29, 1997.

The geophysical exploitation of satellite data requires a high level of accuracy to be maintained over the lifetime of the experiment. The consistency between sensors operating on different platforms must also be studied. It is therefore of prime importance to characterise, by means of intensive validation programmes relying on well-controlled correlative measurements, the sensitivity of both the measurement and the retrieval algorithms to a variety of instrumental as well as atmospheric parameters. The independent calibration and validation of satellite experiments is precisely a main goal of the Network for the Detection of Stratospheric Change (NDSC). This ground-based network of high-quality remote-sounding stations combines various observation techniques and provides measurements of atmospheric ozone and other key constituents from pole to pole, at 17 sites distributed in five primary stations (Arctic, Alpine, Hawaii, New Zealand, Antarctic), and two dozen complementary sites.

NDSC-based studies have already contributed significantly to the validation and maturation of geophysical products from the TOMS series and the ERS-2 GOME (see Lambert *et al.*, 1998a, and references therein). Lambert *et al.* reported a preliminary ground-based characterisation of GOME, TOMS-EP and TOMS-AD total ozone based on data acquired from summer 1996 through May 1997. The main findings of the study consisted of: (a) a reasonable general agreement in the northern hemisphere under normal geophysical conditions; (b) a systematic SZA dependence with TOMS beyond 80° and a seasonal SZA dependence with GOME beyond 70°; (c) an interhemispheric difference of TOMS with the ground-based observations; (d) a difference of sensitivity to ozone between the GOME and ground-based sensors at high latitudes; and (e) a difference of sensitivity with all the satellite observations of low ozone columns in the southern Tropics. The study proposed possible issues, namely, for TOMS V7, refinements of the climatology used in the algorithm and possible calibration problems in the southern hemisphere, and for GOME 2.0, an iterative treatment of the profile shape effect, the use of a column-resolved climatology based on real profile measurements, and refinements of the current spectral analysis approach. The primary purpose of the present paper is to extend this limited, preliminary analysis to the total ozone data records available after several years of operation. The investigation includes one year of GOME data processed with the new operational version of the GOME Data Processor (GDP 2.3), and TOMS-AD data obtained after recent re-calibration of the whole data set.

DESCRIPTION OF THE DATA SETS

The satellite data records studied here extend from the beginning of operation of the instruments through June 1998 for ERS-2 GOME and TOMS-EP, and to June 29, 1997, for TOMS-AD. The GOME ozone data set currently available was obtained with two close versions of the GOME Data Processor. GDP 2.0 had been used in 1996 and 1997. In January 1998, an improved version of the algorithm (GDP 2.3) was implemented for operational processing. Total ozone data from July through December 1995 were also derived from GOME measurements using GDP 2.3. The TOMS data records studied here were processed with the version 7 of the retrieval algorithm. TOMS-EP total ozone consists of overpass data delivered in near real-time since July 1996. TOMS-AD total ozone was recently reprocessed after re-calibration of the entire TOMS-AD data set.

In the framework of the NDSC, about 16 SAOZ (Système d'Analyse par Observation Zénithale) instruments (Pommereau and Goutail, 1988) and two other NDSC-qualified UV-visible spectrometers designed respectively at the Belgian Institute for Space Aeronomy (Van Roozendael *et al.*, 1995) and at the Norwegian Institute for Air Research, perform network operation at primary and complementary sites, from the Arctic to the Antarctic. Twice daily, the ozone total column is derived from their twilight observations of zenith-scattered light. Total ozone is also monitored at NDSC stations with Dobson and Brewer ultraviolet spectrophotometers. The present study relies on correlative observations from the SAOZ/UV-visible network and from Dobson and Brewer spectrophotometers operating at selected sites of the NDSC Alpine and Antarctic stations. The contributing instruments are listed in Table 1. The error on individual total ozone measurements may be estimated roughly to fall within (e.g., Van Roozendael *et al.*, 1998; Lambert *et al.*, 1998a, and references therein): (a) with well-maintained Dobson and Brewer instruments, 0.3-1% under conditions of high sun, clear sky and low ozone, and up to 5-7% at lower sun elevation and in polar winter; (b) with well-maintained UV-visible spectrometers, 2 to 3.5% at middle latitudes, and about 5% in polar winter. To ensure data quality, ground-based total ozone sensors participate regularly to major

Table 1. Contributing Stations and Instruments

Station	Location	Latitude	Longitude	Instrument	Institution
Ny-Ålesund	Spitsbergen	79° N	12° E	SAOZ+, UV-visible+	NILU
Longyearbyen	Spitsbergen	78° N	16° E	UV-visible+	NILU
Thule	Western Greenland	76° N	69° W	SAOZ	DMI
Scoresbysund	Eastern Greenland	70° N	22° W	SAOZ	CNRS/DMI
Sodankylä	Finland	67° N	27° E	SAOZ	CNRS/FMI
Zhigansk	Eastern Siberia	67° N	123° E	SAOZ	CNRS/CAO
Harestua	Norway	60° N	10° E	UV-visible+	IASB
Aberystwyth	United Kingdom	52° N	4° W	SAOZ	U. Wales
Hohenpeißenberg	Germany	48° N	11° E	Dobson[D], Brewer[D]	DWD
Jungfraujoch	Switzerland	47° N	8° E	SAOZ+	IASB
Arosa	Switzerland	46° N	9° E	Dobson, Brewer	ETH
Bordeaux	France	46° N	1° W	Dobson[D]	U. Bordeaux
Haute Provence	France	44° N	6° E	SAOZ, Dobson	CNRS, U. Reims
Tarawa	Kiribati	01° N	173° E	SAOZ	CNRS/NIWA
Saint-Denis	Reunion Island	21° S	55° E	SAOZ	CNRS/U. Reunion
Bauru	Brazil	22° S	49° W	SAOZ	CNRS/UNESP
Kerguelen	Kerguelen Islands	49° S	70° E	SAOZ	CNRS
Faraday/Vernadsky	Antarctica	65° S	64° W	Dobson[DZ], SAOZ+	BAS/KTSU, BAS
Dumont d'Urville	Antarctica	66° S	140° E	SAOZ	CNRS
Rothera	Antarctica	68° S	68° W	SAOZ+	BAS
Halley	Antarctica	76° S	27° W	Dobson[DZ]	BAS

+UV-visible data including a climatological treatment of the profile shape effect.
[D]daily means only; [Z]zenith-sky data included for cloudy days.

field intercomparison campaigns organised through the NDSC and/or the World Meteorological Organization (WMO). In September 1994 at Camborne (UK), the agreement between four SAOZ and seven other UV-visible ozone sensors was within 3%, as well as with the co-located Dobson and integrated ozonesonde profiles (Vaughan *et al.*, 1997). At the Tenth WMO Dobson Intercalibration Campaign held at Arosa in July-August, 1995 (WMO, 1995), the mean bias between the Dobson and Brewer #40 was less than 1%, and less than 1.6% with SAOZ #13 operated at the same site for intercomparison purposes. Scattered light measurements are known to be sensitive to the shape of the ozone profile and scattering geometry, mainly through the so-called air mass factor (AMF) used to convert column densities along the line of sight into vertical column abundances. If not included in the AMF calculation, which is the case for real-time SAOZ data, the latitudinal and seasonal changes of the profile shape effect generate in the zenith-sky data an erroneous latitudinal variation of -3% at 67°N to +2.8% at the Tropics, and a seasonal variation of about 5-6% at 67°N, 3-4% at 44°N, and negligible in the Tropics (Høiskar *et al.*, 1997; Van Roozendael *et al.*, 1998; Denis *et al.*, 1995). When relevant, this latter effect is taken into account in the present correlative study.

To attenuate in the comparison the scatter arising from spatial differences in the air masses sampled by GOME and by the zenith-sky spectrometers, GOME ground pixels are selected such as the line of sight of the satellite matches at best the actual location of the correlative ground-based measurements (Lambert *et al.*, 1998b), resulting in several ground pixels a day. Unless specified in Table 1, the comparison with Dobson and Brewer measurements is restricted to direct sun observations, which are known to be more accurate, and to data points co-located within 300 km and 3 hours between the ground-based measurement and the satellite overpass.

GLOBAL CONSISTENCY

For each ground-based data record, absolute and relative differences with satellite data have been investigated systematically with respect to relevant parameters, namely the SZA and the air mass factor of the space-based measurement, the ozone column value, the tropospheric cloud cover, the possible occurrence of polar stratospheric clouds, the relative position of the polar vortex, and stratospheric temperatures. After taking properly into account the known biases of the ground-based total ozone time-series (e.g., seasonal/latitudinal variation in real-time SAOZ data, or temperature dependence of the ozone absorption coefficients for the Dobson and Brewer instruments), comparison results based on different ground-based observation techniques generally are consistent within the accuracy level of the ground-based data. A consistency by latitude belt is also noticed.

In the Alps, the average agreement between the GOME and ground-based total ozone falls within ±2-4%. At higher latitudes, the signature of a SZA dependent difference appears, which varies with the latitude and the season. The SZA dependence is observed in both hemispheres, however slightly more pronounced in the south, and already detectable at 50°S. The SZA dependence is found to combine with a difference of sensitivity at low ozone column values, compared to ground-based observations. This difference of sensitivity is also noticeable around the southern Tropics.

The average agreement between the TOMS and ground-based total ozone is better than ±2-3% at northern middle latitudes. The agreement at higher latitudes depends on the SZA. The shape of the SZA dependence is similar in both hemispheres and does not vary with the season. The most striking feature of both TOMS-EP and TOMS-AD total ozone data is the pseudo interhemispheric difference of their agreement with ground-based observations as well as with GOME data. At the southern Tropics, a small difference of sensitivity appears compared to the SAOZ.

The qualitative analysis of global ozone maps derived from GOME, TOMS-EP and TOMS-AD data, concludes that the three spaceborne sensors capture similarly the spatial structure of the total ozone field. The comparison of the space- and ground-based time-series leads to similar conclusions for the day-to-day variability of the ozone column, under normal conditions as well as during springtime polar ozone depletion. The quantitative comparison of time-series does not reveal any significant long-term drift. Although mutually consistent within a few percent, systematic differences are observed between TOMS-AD and TOMS-EP total ozone. They might be attributed partly to air mass differences in time (the orbits of ADEOS and Earth Probe are different) and in space (the lines of sight and resulting ground pixels are different), and partly to calibration uncertainties. No significant difference is observed between TOMS-AD data prior to and after the recent re-calibration performed at NASA/GSFC.

SOLAR ZENITH ANGLE DEPENDENCE

The GOME SZA dependence depends on several parameters. A complete description falls beyond the scope of the present paper, and only major features are summarised here. In general, the deviation of GOME from ground-based data does not exceed ±4% below 70° SZA. Beyond 70° SZA, the mean agreement is dominated by a seasonal component and can even vary from month to month, as confirmed by other studies (e.g., Hansen *et al.*, 1998). Figure 1 shows typical comparison results at the Arctic polar circle, separated by season. Between 70° and 85° SZA, the mean difference remains lower than ±4% in winter, but, in summer-fall, it decreases down to 5-10%, with a minimum at 75°-80° SZA. Beyond 85° SZA, the GOME total ozone values increase compared to those measured between 70° and 85° SZA. The shape and the seasonal variation of the GOME SZA dependence are similar in both hemispheres, however slightly more pronounced in the south. The SZA/latitudinal dependence of GOME total ozone is most likely to be attributed to the inaccurate treatment of the profile shape effect, addressing among others possible problems with the ozone profile climatology used in the retrieval algorithm, and the partial unsuitability of the particular spectral analysis approach of GDP when the atmosphere becomes optically thick, which is the case at large SZA in the UV spectral region where GOME total ozone is retrieved.

The SZA dependence between both TOMS and ground-based total ozone in the northern hemisphere is depicted in Figure 2. At low and moderate SZA, the TOMS instruments report in the Arctic larger total ozone values by 3-5% on average in summer-fall, while the agreement is better in wintertime. Beyond 80° SZA, the TOMS columns are smaller by 5-10% on average. A SZA dependence similar in shape and amplitude is observed in Antarctica, but there the mean relative difference is dominated by the systematic bias described in a next section. The notable difference between the GOME and TOMS SZA dependence arises mainly from basic algorithm differences in the treatment of the profile shape effect, and vindicates the use of an iterative approach using a climatology based on real profile measurements (TOMS V7) rather than a one-step approach based on modelling results (GDP 2.x).

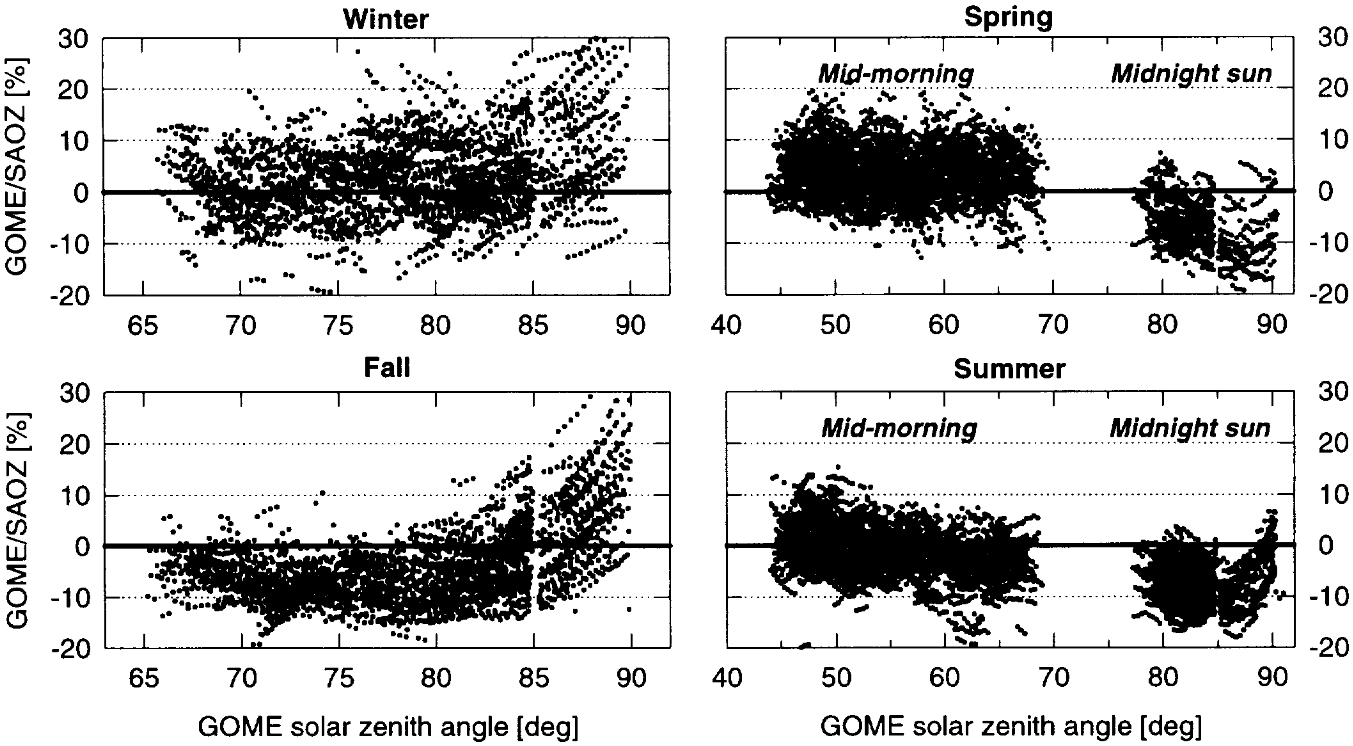

Fig. 1. Solar zenith angle dependence of the relative difference between the GOME and SAOZ total ozone at Sodankylä. Results are depicted by season and include both GDP 2.0 and GDP 2.3 data. In spring and summer, the SZA dependence appears clearly between GOME data acquired during mid-morning and midnight sun overpasses of this Arctic station.

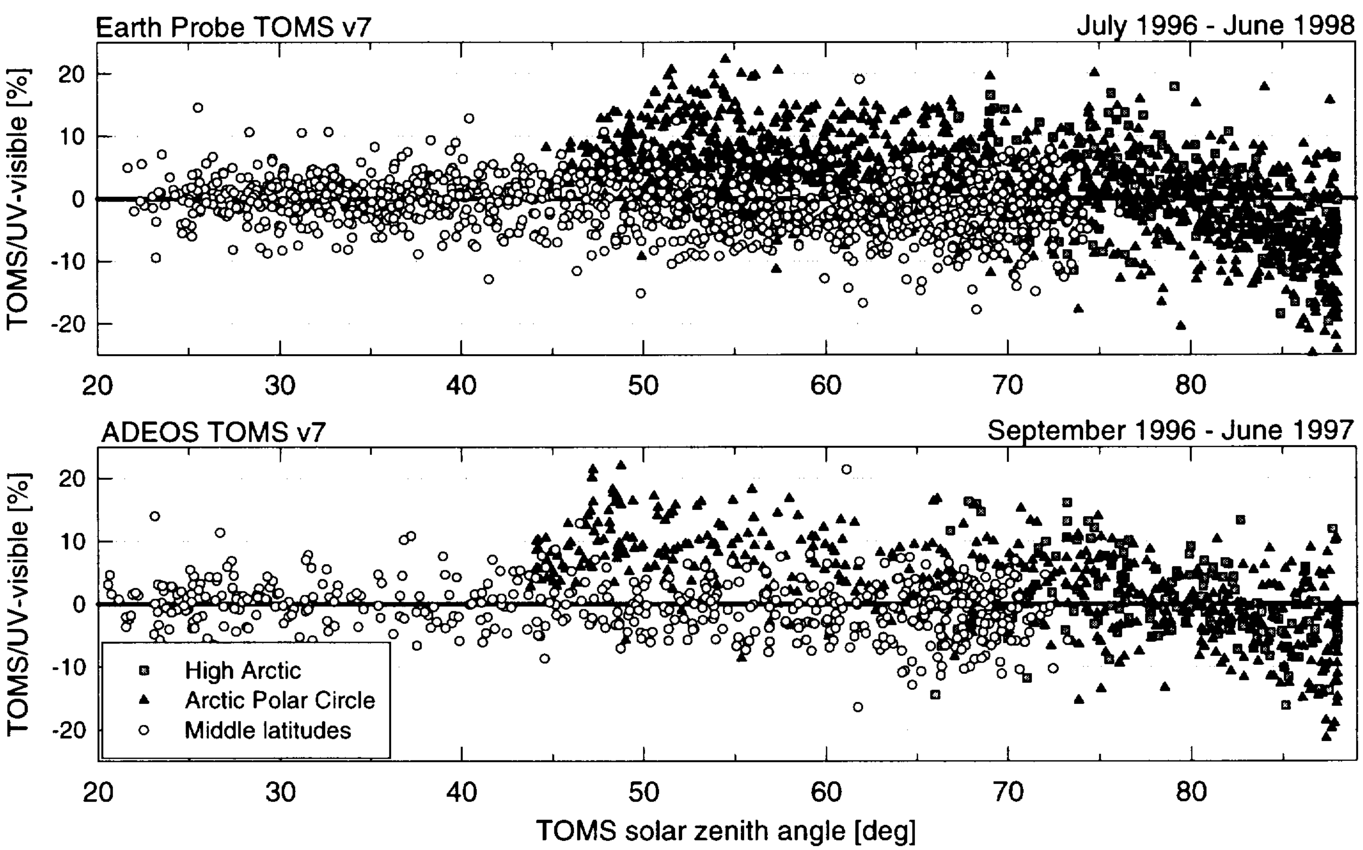

Fig. 2. Solar zenith angle dependence between the ozone total column measured in the northern hemisphere by both TOMS and by 10 ground-based SAOZ/UV-visible spectrometers.

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Attachment